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A. Task Objective: Algorithm Development for Global Mapping of Phycoerythrin Pigment, Dissolved Organic Matter, and Chlorophyllous Pigment

This individual section is essentially as given during the prior quarter. During the prior reporting period, we described a significant advance in the retrieval of inherent optical properties (whose list includes phycourobilin absorption coefficients and phycoerythrobilin absorption coefficients) as published in JGR. The algorithm method is a major departure from the radiance ratios used in the old CZCS algorithms. The new method is based on radiance models derived from the radiative transfer equation (RTE). The linear matrix inversion technique is detailed in: Hoge, Frank E. and Paul E. Lyon, "Satellite Retrieval of Inherent Optical Properties by Linear Matrix Inversion of Oceanic Radiance Models: An Analysis of Model and Radiance Measurement Errors", Jour. Geophys. Res. 101, 16,631- 16,648, (1996). This theoretical work has now been extended to include phycourobilin and phycoerythrobilin absorption coefficients within the matrix inversion. The method forms the basis for the ATBD that appears at http://eospso.gsfc.nasa.gov/atbd/modistables.html as ATBD-MOD-27. It has been found by using airborne radiance data that models for total constituent backscatter are pacing items in improving the accuracy of the retrievals. These are of course under intense development within our project. The principal advantage of the matrix inversion method is that it can be extended to include any number of absorbers and backscatterers. Thus it possesses unlimited potential for general algorithm development for retrieval of inherent optical properties and resultant constituent concentrations.

B. Additional Task Objective: Airborne Validation of MODIS Ocean Products and Algorithms

This Additional Task Objective was added during the last semi-annual reporting period to reflect the added emphasis that the EOS the MODIS Team Leader the MODIS Ocean Team Leader place on validation of ocean products. Validation is defined as the process of establishing the spatial and temporal error fields for a given product or a given algorithm. The validation of MODIS ocean products and algorithms is a major undertaking that will require strategic use of relatively limited resources. Much of the validation afforded the Coastal Zone Color Scanner (CZCS) was performed from research vessels. The technology associated with instrumentation for moored arrays and airborne platforms had not sufficiently matured during the 1978 - 1986 CZCS data collection period to permit sensors from these platforms to play a more significant validation role. Innovation in remote sensor design and advances in technology during the past decade have led to the development of suitable instrumentation for deployment on moored and aircraft platforms. Some of these sensors have measurement capabilities traditionally associated only with ship platforms and are now capable of significantly complementing the sampling and measurement capability of research vessels for validating certain MODIS ocean color products. For some other MODIS ocean products the remote sensors are not yet sufficiently accurate to provide validation without complementary ship observations. Still other MODIS ocean color products will, for the near future, be dependent almost entirely on ship derived observations.

It has long been recognized that ship, aircraft, and mooring platforms each occupy unique niches in the space/time aspect related to ocean color satellite validation. Moorings can effectively provide a time-series of validation measurements lasting several months, often without attention. Modern moorings are generally equipped to hold a variety of sensors. Current technology often permits the telemetry of measurements through a satellite link such that the moored sensor data is available in essentially real-time. The primary limitation of moored sensors is the restrictive spatial coverage that they afford. Due to the stationary nature of moored platforms, measurements derived from their attached sensors are essentially limited to a single pixel of an ocean color image. Nonetheless, the corroborating measurements from the moored sensor suite can often significantly enhance confidence in ocean color products derived over a considerable portion of a scene. Likewise, repetitive observations in conjunction with satellite overpasses serves to provide assurance in the instrument stability during long time periods when sensors on ship and aircraft platforms are not available.

Airborne sensors have the considerable advantage of being able to acquire contemporaneous measurements that are nearly synoptic over a wide area with corresponding satellite ocean color sensor observations. The spatial extent over which the airborne measurements can be considered sufficiently synoptic for validation purposes is dependent on the physical dynamics of a particular oceanographic province. Nonetheless, since these physical changes are temporal in nature, the spatial coverage afforded by either an aircraft or a ship platform is directly proportional to the speed of the respective platform. Aircraft, such as the NASA P-3B or C-130, routinely cruise at speeds between 130 and 140 m/sec (~250 and ~270 knots), which is approximately 25 - 27 times the speed of a research vessel engaged in along track sampling. Thus, if a 40 km cross-section of ship measurements (acquired during a one hour period surrounding the passage of an ocean color sensor) can be considered sufficiently synoptic for routine validation purposes, then an aircraft similarly engaged could provide a 1,000 km cross-section for direct validation of satellite ocean color products. Often a variety of different sensors can be packaged together and flown on the same aircraft platform to provide a data set of complementary measurements where each individual measurement is enhanced by the presence of the other measurements in the ensemble. The main concern about ocean color product validation from an aircraft platform is in the area of measurement accuracy. As with moored sensors, considerable improvements have been made to aircraft sensors in recent years such that the measurement accuracy for certain ocean color products is compatible with ship measurements of the same parameter. Still other ocean color products can be measured remotely from an aircraft platform to within acceptable validation standards with the aid of contemporaneous ship observations.

Research vessels are a valuable resource for validating ocean color products. Modern research vessels are capable of housing a variety of instruments, sensors, and laboratory equipment for making a diverse suite of measurements useful for validating ocean color products. Some of these measurements cannot be made from mooring or aircraft platforms. Research vessels are equipped with laboratories for filtering and extracting pigments, have flow through plumbing from which instruments can continuously sample water from the surface layer, can deploy highly technical towed fish (such as the SeaSoar), can carry a variety of optical and biochemical sensors, and are capable of maintaining stations where primary productivity measurements can be conducted. Optical measurements can be made in conjunction with a variety of biogeochemical observations from essentially the same parcel of water. This aspect is particularly valuable in developing models used in the retrieval of ocean color products from MODIS ocean color imagery. Research vessels can collect time-series observations in conjunction with ocean color satellite overpasses, although generally over a shorter time frame than is possible with moored sensor arrays. They also can make measurements over some portion of an ocean color image, although the size of the "near synoptic" sampling region is roughly only 1/25th that of an aircraft platform. It is these temporal and spatial sampling restrictions of a ship platform for validating ocean color products that make the use of mooring and aircraft platforms in concert with some ship sampling essential. In accordance with goals of improving our validation, we place our Shipboard Laser Fluorometer (SLF) aboard Dr. William (Barney) Balch's November, 1997 cruises to obtain high spectral resolution phycoerythrin, chlorophyll, and water Raman scatter data. This initial test of the SLF was highly successful, with more than 10 days of continuous data obtained in 12 hour segments. For the first time the PUB induced spectral shit of PEB was seen in the flow-through data without the need of time consuming concentration and/or filtering of samples. Additional SLF data acquisition is planned for the cruise of Dr. Patti Matri (Bigelow Laboratories) aboard the RV Hatteras in March of 1998.

This new, additional validation thrust is the result of communication between this MODIS investigator, the MODIS Ocean Discipline Team Leader, and the MODIS Team Leader. It will become the major priority as MODIS launch approaches and the need for calibration and validation becomes still more critical. The phycoerythrin effort will be allowed to flow naturally from the principal calibration and validation effort.

In concert with our added emphasis on validation, we have intensified our calibration effort. To this end we are pleased to report that Mr. Thomas Riley (GSFC Greenbelt) traveled to Wallops as a part of his world wide calibration round robin. The preliminary results look quite good for our new reflectance-plaque and standard 200 watt lamp calibration system as now configured in a specially built room-in-a-room calibration facility at Wallops. The calibration sphere, used for many years showed lower precision and will probably not be used of passive radiometric calibration in the future.

1. MODIS North Atlantic Test Site Establishment and Characterization

The Test Site includes the New York Bight/Mid-Atlantic Bight/Gulf Stream/Sargasso Sea and is conveniently located north and east of GSFC/WFF. As previously reported, the MODIS North Atlantic Test Site has been established as originally proposed. Much of the data obtained in the northwestern portion of the test site will be used for algorithm development in Case 2 waters. Characterization has been initiated by ship sampling, aircraft overflights, and analysis of historical data available from within the NASA AOL project since 1980.

It is expected that the MODIS North Atlantic Test Site will be further used for validation of MODIS ocean products and algorithms.

a. During this semiannual reporting period airborne missions were flown in the MODIS Test Site on August 12-15 over the research vessel RV Cape Henlopen (Dr. Neil Blough, U MD Chief Scientist). SeaWiFS underflights were also conducted Dec 16, 1997 in order to test our ability to validate MODIS products. We also overflew Dr. William (Barney) Balch Nov 17, 1998 during his cruise of Gulf of Maine and Georges Bank. This cruise carried the SLF instrument and these data are also undergoing processing and analysis. These missions allow us to refine the techniques to provide validation data for (a) chlorophyll, (b) CDOM, and (c) water-leaving radiances, (d) down-welling irradiance, and (e) sky radiance. Concurrently this data allows further progress on the development of algorithms for chlorophyll and CDOM retrievals. They will also provide additional evaluation of the recently-rebuilt AOL system and will provide data needed to further calibrate the fluorescence/Raman ratios derived from the AOL spectrometer data to retrieve CDOM and chlorophyll absorption coefficients. Data from the Japanese OCTS sensor concurrently with airborne active-passive (laser-solar) data is being analyzed to for possible improvements to the MODIS phytoplankton absorption and CDOM absorption retrieval algorithms. In turn the phycoerythrin retrieval algorithm will be improved.

Furthermore, and as previously suggested in a prior report, the above airborne flights allow continued evaluation of a new 256 channel ocean color spectroradiometer designed and built at Wallops Flight Facility. It was found that the color sensor possessed the requisite sensitivity for ocean color spectra in a high-rate/low-integration-time mode needed to allow editing of data containing sun glint. Initially, the prototype sensor was successfully flown during the JGOFS Iron Enrichment Experiments off the coast of Ecuador in November 1993. A still higher sensitivity detector and higher resolution sensor was successfully flown in March 1995 and during the JGOFS Arabian Sea Experiment. Evaluation of the data suggests that it is of good quality.

b. Other Data Acquisition for Algorithm Development/MODIS Validation

New Algorithm Method. As reported in the last semi-annual report, a significant advance in the retrieval of inherent optical properties (whose list includes phycourobilin absorption coefficients and phycoerythrobilin absorption coefficients) was published last year. The algorithm method is a major departure from the radiance ratios used in the old CZCS algorithms. The new method is based on radiance models derived from the radiative transfer equation (RTE). The linear matrix inversion technique is detailed in : Hoge, Frank E. and Paul E. Lyon, "Satellite Retrieval of Inherent Optical Properties by Linear Matrix Inversion of Oceanic Radiance Models: An Analysis of Model and Radiance Measurement Errors", Jour. Geophys. Res. 101, 16,631-16,648, (1996). Work is now underway to extend the method to include phycourobilin and phycoerythrobilin absorption coefficients within the matrix inversion. No problems are anticipated with this effort.

These passive retrieval methods, while important for algorithm development, allow us to advance the very techniques that will be used to provide validation for MODIS ocean products.

c. The laser receiver modifications previously reported during 1995 have been very successful. As we reported, in order to improve the laser measurement of phycoerythrin, the Airborne Oceanographic Lidar (AOL) was rebuilt during that reporting period to lessen the persistent stray light scatter problem in the spectrometer. The modifications included removal of the rigid light-guides and all turning mirrors comprising the original optical axis. A fiber optic face plate now occupies the focal plane of the new in-line optical path and transports the spectral radiation to mechanically reconfigured banks of original photomultiplier tubes. The resolution of each channel of the fiber optic face plate system is ~4nm but were optically combined at the photomultiplier tube face to achieve ~12nm per channel for this experiment. The signal path from the photomultiplier tubes through and including digitization remain essentially the same as reported previously. Compared to the original light guides, the fiber optic channels have superior scattered light rejection ascribed to a considerably smaller viewing or acceptance angle. Furthermore, a Bragg diffraction filter in the collimated segment of the light-path blocks passage of 532nm radiation to the diffraction grating and subsequent fiber optic focal plane. The 532nm pulse reflected from the Bragg diffraction filter is used to temporally define the ocean surface target and initiate digitization of the fluorescence spectra. A spectral and radiometric calibration is performed before and after each flight mission by viewing an internally illuminated 0.75m diameter calibration sphere placed beneath the aircraft telescope viewing port. Immediately following the 0.75m sphere calibration, a separate on-board 10cm calibration sphere is viewed by mechanically introducing (at the focal plane of the telescope) fiber-optically-delivered radiation from a tungsten lamp (followed by 40ns pulsed red LED's). The small calibration sphere allows immediate transfer of the 0.75m sphere calibration into the aircraft domain. The pulsed LED's then provide transfer of the ground (and onboard) DC tungsten lamp calibrations to the wide bandwidth pulsed portion of the AOL detection/amplification/digitization system. Calibration is maintained in flight by periodically viewing the 10cm calibration sphere. Complete details of the new AOL configuration are excepted to be described in other publications.

B. Other Work Accomplished

We did overfly Dr. Neil Blough his August 11-17, 1997 cruise from Delaware Bay to the Gulf Stream then Chesapeake Bay and home port.

The planned overflights of the cruise of Dr. Barney Balch in the Gulf of Maine in early June were cancelled due to aircraft mechanical problems. This was a severe dissappointment since the combined ship-aircraft data would have allowed important tests of our ability to validate the total constituent backscatter coefficient. However, as reported herein his subsequent cruise was successfully overflown on Nov. 17, 1997.

3. Satellite Data Analysis

We requested and received the Feb 24, 1997 OCTS data for the East Coast-US. Initial processing with SeaDAS software yields a troubling finding: the 412nm band data are mostly null values. Actually, the 412nm data is probably negative (physically unrealizable) and is set to zero during processing. We are continuing to work with Greenbelt folks to resolve the data problem. This particular OCTS image is important since airborne underflight data was taken concurrently. According, products since we have contemporaneous airborne laser data for this date.

D. Anticipated Activities During Next Half Year.

1. As previously discussed, additional flights of the NASA Airborne Oceanographic Lidar are planned within the MODIS Test Site. Specifically, overflights of cruises of the research vessels in conjunction with the ONR/Univ. MD (Dr. Neil Blough) in the MAB, and over Dr. Barney Balch in the Gulf of Maine, and over Dr. John Brock in the SAB. Planned flights include the clear-day cruises of Dr. William (Barney) Blach on a ferry boat from Portland, Maine to Yarmouth, Nova Scotia in Fall 1998.

2. No international field excursions are planned during 1997.

E. Recent Publications

1. Hoge, Frank E. and Robert N. Swift, Development and validation of satellite retrieval algorithms and derived products: An emerging role for airborne active-passive (laser-solar) ocean color remote sensing, Paper 2964-06, SPIE Special Edition, Volume 2964, 92-99, (1996).

2. Hoge, Frank E. and Paul E. Lyon, "Satellite Retrieval of Inherent Optical Properties by Linear Matrix Inversion of Oceanic Radiance Models: An Analysis of Model and Radiance Measurement Errors", Jour. Geophys. Res. 101, 16,631- 16,648, (1996).

3. Hoge, F.E., M.E. Williams, R.N. Swift, J.K. Yungel, and A. Vodacek, Satellite retrieval of the absorption coefficient of chromphoric dissolved organic matter in continental margins, Jour. Geophys. Res. 100, 24847-24854, (1995b).

4. Hoge, Frank E., Robert N. Swift, and James K. Yungel, Oceanic radiance model development and validation: Application of airborne active-passive ocean color spectral measurements, Applied Optics, 34, 3468-3476, (1995).

5. Hoge, Frank E., Anthony Vodacek, Robert N. Swift, James Y. Yungel, Neil V. Blough, Inherent optical properties of the ocean: Retrieval of the absorption coefficient of chromophoric dissolved organic matter from airborne laser spectral fluorescence measurements, Applied Optics, 34, 7032-7038, 1995.

F. Other Concerns

The retirement of the NASA/GSFC C-130Q aircraft is a major concern. This will leave only the already-crowded P-3B for major field validation missions. Thus, our eventual size/power/weight/volume reduction of the AOL and use of smaller airborne platform is considered mandatory.

As reported previously, the lack of a 600nm band on MODIS-N is no longer felt to be the biggest problem facing the retrieval of the phycoerythrin pigment. Additional effort since the last report still suggest that radiance (and reflectance) models, can provide retrieval of the phycoerythrin pigment at the absorption peaks of

495nm (phycourobilin, PUB) and 545nm (phycoerythrobilin, PEB) can be achieved using the 490nm and 555nm MODIS bands. Of course, such retrievals will require a highly accurate model to account for the significant amounts of chlorophyll and DOM absorption occurring simultaneously with the phycoerythrin absorptions. The details of the phycoerythrin retrieval have been recently detailed in the ATBD but are being upgraded to linear matrix inversion of a radiance model that includes the phycoerythrobilin and phycourobilin absorption coefficients